CRITERIA FOR IDENTIFICATION OF LODGEMENT TILL, MELT-OUT TILL, AND GRAVITY FLOWTILL

After Dreimanis, 1988.

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<tr><th>Criterion</th><th>Lodgement till</th><th>Melt-out till</th><th>Gravity flowtill</th></tr>
<tr><td>Position and sequence in relation to other glacigenic sediments</td><td>Under advancing glacier: lodged over older pre-advance sediments and over glacitectonites, unless they have been eroded. Under retreating glaciers: the lower-most depositional unit, if the deposits related to glacial advance have been eroded. Locally underlain by meltwater channel deposits. May be overlain by any glacigenic sediments.</td><td>Usually deposited during glacial retreat over any glacially- eroded substratum, or over lodgement till. Also as lenses in lodgement till. May be interbedded with lenses of englacial meltwater deposits, and locally is underlain by syndepositional subglacial meltwater sediments and subglacial flowtill. At the surface, melt-out till grades into flowtill, and in cold arid climates into sublimation till, as a specific variety of melt- out till.</td><td>Most commonly it is the uppermost glacial sediment in a non- aquatic facies association. Associated also locally with subglacial tills, where cavities were present under glacier ice, or where the glacier had over-ridden the ice-marginal flowtill. May be interbedded or interdigitated with glaciofluvial, glaciolacustrine or glaciomarine sediments, particularly away from its original source at the glacier ice.</td></tr>
<tr><td>Basal Contact</td><td colspan="2">Since both lodgement and melt-out tills begin their formation and deposition at the glacier sole, their basal contact with the substratum (bedrock or unconsolidated sediments) is similar in large scale, being usually erosional and sharp. The glacial erosion-marks underneath the contact and the alignment of clasts immediately above the contact have the same orientation. Glacitectonic deformation structures formed by the till-depositing glacier may occur under both tills, and they strike transverse to the direction of local glacial stress.</td><td>Variable; seldom planar over longer distances. The flows may fill shallow channels or depressions. The contact may be either concordant, or erosional, with sole marks parallel to the local direction of sediment flow. Loading structures may be present at the basal contact of waterlain flowtill and the underlying soft sediment.</td></tr>
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	Basal contact, representing the sliding base of the glacier, is generally planar if over unconsolidated substratum, but it may be grooved. The bedrock contact is usually abraded, particularly on stoss sides of bedrock protrusions. Since the sliding base of the glacier represents a large shear plane, sheared and strongly attenuated substratum material may be deposited in a thin layer along this plane, and from place to place it is sheared up into the lodgement till. Clast pavements, both erosional and depositional, may be present along the basal contact, but they occur also higher up in lodgement till. If lodgement till becomes deformed by glacial drag shortly after its deposition, the basal contact may become involved in the deformation by tight recumbent folding, overthrusting, and shearing.	If the basal contact of glacier ice was tight with the substratum during the melting, the pre-depositional erosional marks characteristic for moving glaciers, are as well preserved as under lodgement till. However, subsole meltwater may modify the basal contact locally, and produce convex-up channel fills and various other meltwater scour features.	

Surface expression landforms	Mainly in ground moraines and other subglacial landforms. Also along the proximal side of some end moraines. Small-scale flutes are always associated with lodgement till.	In those ice-marginal landforms where glacier ice had stagnated.	Associated with most ice marginal landforms. Also as a thin surface layer on many other direct glacial landforms.

Thickness	Typically one to a few meters; relatively constant laterally over long distances.	Single units are usually a few centimeters to a few meters thick, but they may be stacked to much greater thicknesses.	Very variable. Individual flows are usually a few decimeters to meters thick, but they may locally stack up to many meters, particularly in ablation moraines and some lateral moraines.
Structures, folding, faulting	Usually described as massive, but on closer examination, a variety of consistently oriented macro- and micro-structures indicative of shear or thrust may be found. Folds are overturned, with anticlines attenuated downglacier. Deformation structures are particularly noticeable, if underlying sediments are involved, or incorporated in the till, developing smudges. Subhorizontal jointing or fissility is common. Vertical joint systems, bisected by the stress direction, and transverse joints steeply dipping down-glacier, may be formed by glacier deforming its own lodgement till. The orientation of all the deformation stuctures is related to the stress applied by the moving glacier, and therefore it is laterally consistent for some distance.	Either massive, or with palimpsest structures partially preserved from debris stratification in basal debris-rich ice. Lenses, clasts, and pods of texturally different material preserve best, for instance soft-sediment inclusions of various sizes, and englacial channel-fills. Loss of volume with melting leads to the draping of sorted sediments over large clasts. Most large rafts or floes of substratum are associated with melt-out tills, and they may be deformed by glacial transport and by differential settlement during the melting.	The structure depends upon the type of flow and associated other mass movements, the water content and the position in the flow. Either massive, or displaying a variety of flow structures, such as: (a) overturned folds with flat-lying isoclinal anticlines, (b) slump folds or flow lobes with their base usually sloping downflow, (c) roll-up structures, (d) stretched-out silt and sand clasts, (e) intraformationally sheared lenses of sediments incorporated from substratum, with their upper downflow end attenuated, if consisting of fine-grained material, or banana shaped, (f) diapirs injected by dewatering and drawn out into flame structures, (g) small to medium-scale stringers of silt displaying a variety of flow patterns (shears, folds, etc.) (h) load structures, particularly in the lower part of flows. The orientation of structures is related to the local stress, and therefore the orientation varies from place to place. Melting of underlying ice may produce local sagging in the structures, or gravity faulting.

Grain size composition	Usually a diamicton, containing clasts of various sizes. Grain- size composition depends greatly upon the lithology and grain- size composition of the substrata up-glacier and the distance and mode of transport (basal, englacial) from there. Comminution during glacial transport and lodgement has produced a multimodal particle size distribution. Most resulting subglacial tills are poorly to very poorly sorted, described also as well graded, and their skewness has a nearly symmetrical distribution, except for those tills that are rich in incorporated pre-sorted materials.		Usually a diamicton with polymodal particle size distribution. It is texturally similar to that primary till to which it is related, but with a greater variability in grain size composition, due to washing out of, or enrichment in fines, or incorporation of soft substratum sediments during the flow. Some particle size redistribution takes place during the flow. The grain size composition depends greatly upon the type of flow, and the position or zone in it. Sorting, inverse or normal grading may develop in some zones of flows, and parts of clasts may sink to the base of flow.
	The abrasion in the zone of traction during lodgement produces particularly silt-size particles typical for lodgement tills. Most lodgement tills have a relatively consistent grain-size composition, traceable laterally for kilometers, except for the lower .5 to 1 m that strongly reflects the local material. Clusters or pavements of clasts are common.	The winnowing of silt- and clay-size particles in the voids during the melt-out may reduce the abundance of these particle sizes in some parts of melt-out tills in comparison with their lodged equivalents. Some particle size variability is inherited from texturally different debris bands in ice. Extreme variations in grain size may occur over short distances in the vicinity of large rafts and other inclusions of soft sediment. In supra-glacial melt-out tills of mountain glaciers those melt- out tills are particularly coarse grained which derive mainly from supraglacial debris.	

Lithology of clasts and matrix	Lithologic composition tends to be less variable than in other genetic varieties of tills; most constant is the mineralogic and geochemical composition of the till matrix. Materials of local derivation increase in abundance towards the basal contact of the tills with the substratum.	Lithologic composition tends to be less variable than in other genetic varieties of tills; most constant is the mineralogic and geochemical composition of the till matrix. Materials of local derivation increase in abundance towards the basal contact of the tills with the substratum.	The lithologic composition is generally the same as that of the source material of flowtill - a primary till or glacial debris, plus some substratum material incorporated during the flowage. Material of distant derivation dominates in the flowtills derived from supraglacial and englacial debris, but dominance of local material indicates derivation from basal debris. Soft sediment clasts derived from the substratum, or from sediment interbeds in multiple flows, are common.
		Since glacial debris of distant derivation is more common in the englacial zone than in the basal zone of a glacier, and since the englacial zone has a greater possibility to be deposited as melt-out till, rather than by lodgement, materials of distant derivation may be more abundant in the melt-out till than in the lodgement till of the same till unit, particularly in supraglacial melt-out till. Great compositional variability occurs in the vicinity of incorporated 'megaclasts', 'rafts' or 'floes' of sub-till material. Soft sediment clasts, for instance consisting of sand, may be found in melt-out till, but not in typical undeformed lodgement till.	

Clasts shapes and their surface marks	Following criteria apply to lodgement till and basal melt-out till where most clasts are derived from a single cycle of transport: subangular to subrounded shapes dominate, depending mainly upon the distance of transport in the basal zone of traction. Bullet-shaped ('flat-iron', 'elongate pentagonal') clasts are more common than in other tills and nonglacial deposits, and their tapered ends usually point upglacier. Some of the elongate clasts have a keel at their base. Glacial striae are visible mainly on medium-hard fine-grained rock surfaces. Elongate clasts are striated mainly parallel to their long axes, unless they have been lodged or transported by rolling.	Following criteria apply to lodgement till and basal melt-out till where most clasts are derived from a single cycle of transport: subangular to subrounded shapes dominate, depending mainly upon the distance of transport in the basal zone of traction. Bullet-shaped ('flat-iron', 'elongate pentagonal') clasts are more common than in other tills and nonglacial deposits, and their tapered ends usually point upglacier. Some of the elongate clasts have a keel at their base. Glacial striae are visible mainly on medium-hard fine-grained rock surfaces. Elongate clasts are striated mainly parallel to their long axes, unless they have been lodged or transported by rolling.	If present, soft sediments clasts are either rounded or deformed by shear or dewatering. The more resistant rock clasts are in the same shape as they were in the source material when resedimented by the flowage. Therefore, the relative abundance of glacially- abraded subangular to subrounded clasts versus completely angular clasts in flowtills of mountain glaciers will indicate the approximate participation of basal debris versus supraglacial debris in the formation of the flowtill. Some rounded water-reworked clasts, without striations, may derive in flowtills from melt-water stream deposits.

	The bullet-shaped and faceted clasts, also crushed, sheared and streaked-out clasts are more common in lodgement till than in other tills. Lodged clasts are striated parallel to the direction of the lodging glacial movement, and they have impact marks on both the upper and lower surfaces, but in opposite orientation: on the surface the stoss end is upglacier, but on the underside--the stoss end is downglacier. Clast pavements with sets of striae parallel to the direction of the latest glacial movement over them may occur at several lodgement levels. Their top facets are either parallel with the general plane of lodgement, or they dip upglacier.	If, in an area of mountain glaciation, the source of supraglacial melt-out till is englacially or even supraglacially transported supraglacially- derived debris, then the clasts are angular. Most commonly, supraglacial melt-out till in such areas also contains an admixture of glacially-abraded basal debris, also englacially transported.	
Fabric macro-fabric (orientation of clasts) or micro-fabric (orientation of particles in the matrix)	Strong macro-fabrics with the long axes parallel to the local direction of glacial movement are reported from diamictons identified either as lodgement or melt-out tills. Occasionally transverse maxima have developed, associated with folding and shearing. The fabric strength may vary also, depending upon the grain size of till, the abundance of clasts, and postdepositional modification.	Strong macro-fabrics with the long axes parallel to the local direction of glacial movement are reported from diamictons identified either as lodgement or melt-out tills. Occasionally transverse maxima have developed, associated with folding and shearing. The fabric strength may vary also, depending upon the grain size of till, the abundance of clasts, and postdepositional modification.	Variable, and depending greatly upon the type of flow and the position in the flow. It may range from randomly oriented to strong fabric, in thin flow tills. Fabric maxima are either parallel or transverse to the local flow direction, unrelated to glacial movement; the a - b planes are either subparallel to the base of the flow, or they dip up-flow. Fabric maxima may also differ laterally on short distances.

	The lodgement till fabric may be of complex origin: produced by lodgement, or by deformation of the already deposited dilated till, under the same glacier. If both stress directions coincide, a strong fabric will develop; if not, the lodgement fabric becomes weakened. Typically, the a - b planes dip slightly upglacier, if lodgement alone is involved. The micro- fabric is usually as strong as the macro-fabric.	In melt-out tills, fabric is inherited from glacier transport, where strong fabric dominates, parallel to the direction of glacial movement, unless deformation changes it to transverse fabric locally. However, the melting-out process may weaken the fabric, particularly the micro-fabric. Also, the dip of the inclination of clasts becomes reduced by the reduction of the volume of ice during melting.	

Consolidation, permeability, density	Most lodgement tills, particularly the poorly sorted, matrix- supported varieties, are overconsolidated, provided there was adequate subglacial drainage. Their bulk density, penetration resistance, and seismic velocity are usually high, and permeability is low, relative to other varieties of till in the region.	Supraglacially formed melt-out tills are usually less (normally to weakly) consolidated than the subglacially- formed, commonly overconsolidated melt-out tills, provided there was adequate drainage of meltwater. Bulk density and penetration resistance may be lower and more variable than in related lodgement till. Also, permeability is more variable.	Primarily normally consolidated and relatively permeable. If clayey, may become overconsolidated due to post-depositional dessication. Density lower than in primary tills.